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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Page 2 de l'attestation

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Reflectors for use in lithographic projection apparatus

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Reflectors for use in Lithographic Projection Apparatus

The present invention relates to adaptive reflectors, e.g. for extreme ultraviolet radiation. More particularly, the invention relates to the use of such reflectors in illumination and projection systems of lithographic projection apparatus comprising:

an illumination system constructed and arranged to supply a projection beam of radiation;

a first object table provided with a first object holder constructed to hold a mask;

a second object table provided with a second object holder constructed to hold a substrate;

a projection system constructed and arranged to image an irradiated portion of the mask onto a target portion of the substrate; and

an active reflector comprised in an optical system, being either or both of said illumination system and said projection system, said active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The illumination system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam, and such elements may also be referred to below, collectively or singularly, as a "lens". In addition, the first and second object tables may be referred to as the "mask table" and the "substrate table", respectively.

In the present document, the terms "radiation" and "beam" are used to encompass ultraviolet (UV) radiation (e.g. at a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm) and extreme ultraviolet (EUV) radiation. Also herein, the invention is described

using a reference system of orthogonal X, Y and Z directions and rotation about an axis parallel to the I direction is denoted Ri. Further, unless the context otherwise requires, the term "vertical" (Z) used herein is intended to refer to the direction normal to the substrate or mask surface, rather than implying any particular orientation of the apparatus. Similarly, the term "horizontal" refers to a direction parallel to the substrate or mask surface, and thus normal to the "vertical" direction.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto an exposure area or target portion (comprising one or more dies) on a substrate (silicon wafer) which has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions which are successively irradiated via the mask, one at a time. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — which is commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO 97/33205.

In a lithographic apparatus the size of features that can be imaged onto the wafer is limited by the wavelength of the projection radiation. To produce integrated circuits with a higher density of devices, and hence higher operating speeds, it is desirable to be able to image smaller features. Whilst most current lithographic projection apparatus employ ultraviolet light generated by mercury lamps or excimer lasers, it has been proposed to use shorter wavelength radiation of around 13nm. Such radiation is termed extreme ultraviolet (EUV) or soft x-ray and possible sources include laser-induced plasma sources, discharge plasma sources or synchrotron radiation from electron storage rings. An outline design of a lithographic projection apparatus using synchrotron radiation is described in

"Synchrotron radiation sources and condensers for projection x-ray lithography", JB Murphy et al, Applied Optics Vol. 32 No. 24 pp 6920-6929 (1993).

Lithographic projection apparatus using EUV radiation are intended to image mask patterns with a critical dimension of 90nm or less. This imposes extremely severe accuracy criteria on the illumination and especially the projection optics. For the projection system, the required accuracy is defined by the wavefront aberration (WFA) which is twice the magnitude of the surface figure error. For a four mirror system it has been calculated (Gwyn, C.W. *et al*, Extreme Ultraviolet lithography, J. Vac. Sci. Technol. B 16, (Nov/Dec) 1998, pp 3142) that a WFA tolerance of ≤ 1nm rms is required for low frequency errors, i.e. those of spatial wavelength of greater than 1mm. Independent errors of each mirror must therefore be no greater than 0.25nm, since in a system of N mirrors the maximum permissible error of each mirror is $(2\sqrt{N})^{-1}$ times the total error for the system. For mid-spatial frequency errors, of wavelength 1mm to 1μm, surface roughness must be less than 0.2nm rms as roughness in this spatial frequency range reduces image contrast. High-spatial frequency errors, of wavelength less than 1μm, cause large angle scattering, a loss mechanism for the beam, and so surface roughness for these frequencies must be less than 0.1nm rms.

US 5.986,795 and US 5,420,436 both disclose the use of adaptive mirrors in photolithography using EUV radiation. In the mirror described in US 5,986,795, a number of actuators are provided between a reaction plate and a face plate bearing a reflective coating suitable for the radiation used in the lithography apparatus. The actuators may be piezoelectric, electroresistive or magnetoresistive and act generally perpendicularly to the face and reaction plates. The reaction plate is more flexible than the face plate.
US 5,420,436 describes a similar arrangement, having an array of piezoelectric actuators acting perpendicularly between a reaction plate and a face plate; in this case however the face plate is more flexible than the reaction plate.

It is an object of the present invention to provide an adaptive reflector or system of reflectors, especially for extreme ultraviolet radiation, that can provide improved control over the surface figure of the mirror and hence over wavefront aberration.

According to the present invention there is provided a lithographic projection apparatus for imaging a mask pattern in a mask onto a substrate, the apparatus comprising:

an illumination system constructed and arranged to supply a projection beam of radiation;

a first object table provided with a first object holder constructed to hold a mask;

a second object table provided with a second object holder constructed to hold a substrate;

a projection system constructed and arranged to image an irradiated portion of the mask onto a target portion of the substrate; and

an active reflector comprised in an optical system, being either or both of said illumination system and said projection system, said active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer; characterized in that:

said actuator exerts a substantial force component in a direction parallel to the surface figure of said reflective multilayer.

The actuator in the active mirror serves to control the surface figure of the reflective multilayer and hence can be used to minimize wavefront aberration in the radiation beam delivered by the optical system. Stress, and particularly stress variations, have been identified as a major source of surface figure errors in reflectors adapted to reflect EUV radiation and the invention can directly compensate for this. The present invention can be used to compensate for stress inherent in the multilayer as a result of its manufacture as well as stresses caused by external factors. The actuators may be piezoelectric stack or patch actuators and are preferably incorporated into the reflector body close to the reflecting multilayer.

It is important that the actuators exert a substantial component of force in a direction parallel to the surface figure of the multilayer. In the case of a significantly curved mirror the force component should be parallel to the surface figure at or near the point of connection between the actuator and the multilayer or the member bearing the multilayer. The stiffness of the multilayer, or a member bearing the multilayer, is higher in directions parallel to the surface figure than in the direction perpendicular to the surface figure. (Note that in a local coordinate system having orthogonal x, y and z axes describing the mirror, the direction perpendicular to the surface figure at the center of the mirror may be referred

to as the z-direction.) This means that a given force exerted parallel to the plane of the reflector effects a smaller deformation of the surface figure than the same force exerted perpendicularly. Since the required deformations are very small and actuators of the required strength are easily obtained, the present invention allows for a much more exact control of the surface figure, with reduced risk of over-deforming the mirror.

The actuators may lie wholly in the plane of the reflector, particularly where the actuators are patch actuators. However, the actuators may also be rod actuators arranged diagonally between the reflective layer and base member. In such an arrangement, the actuators may be arranged in pairs connected to the reflective layer at the same point but to the base plate at spaced-apart locations and controlled so that the resultant force exerted by each pair on the reflector layer lies wholly within the plane of the reflector. It is also possible for the actuators to be connected singly but in that case it is preferred that of the force exerted by each actuator on the surface figure, the component perpendicular to the surface is less than 50% and preferably less than 20% of the total force exerted by that actuator.

The present invention also provides a device manufacturing method using a lithography apparatus comprising:

an illumination system constructed and arranged to supply a projection beam of radiation;

a first object table provided with a first object holder constructed to hold a mask;

a second object table provided with a second object holder constructed to hold a substrate;

a projection system constructed and arranged to image an irradiated portion of the mask onto a target portion of the substrate; and

an active reflector comprised in an optical system, being either or both of said illumination system and said projection system, said active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table; and

irradiating said mask with said projection beam whilst imaging an irradiated portion of said mask onto said substrate; characterized in that:

said actuator exerts a substantial force component in a direction parallel to the surface figure of said reflective multilayer; and by the step of:

during said step of irradiating and imaging, controlling said active reflector to minimize wavefront aberration in a radiation beam reflected by said active reflector.

In a manufacturing process using a lithographic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion" or "exposure area", respectively.

The present invention and its attendant advantages will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Fig. 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Fig. 2 is a diagram of relevant components of the projection optics of the first embodiment;

Figs. 3A to 3C are cross-sections of alternative arrangements of bimorph mirrors usable in the first embodiment of the invention;

Fig. 4 is a diagram of a control system used in the first embodiment of the invention;

Fig. 5 is a table of results of two examples of the present invention compared with a static mirror; and

Fig. 6 is a cross-sectional view of an active mirror used in a second embodiment of the invention.

In the various drawings, like parts are indicated by like references.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus 1 according to the invention. The apparatus comprises:

- a radiation system LA, IL for supplying a projection beam PB of EUV radiation;
- a first object table (mask table) MT provided with a mask, or fist object, holder for holding a mask MA (e.g. a reticle), and connected to first positioning means PM for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate, or second object, holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means PW for accurately positioning the substrate with respect to item PL;

- a projection system ("lens") PL (e.g. a refractive or catadioptric system or a reflective system) for imaging an irradiated portion of the mask MA onto a target portion C (die) of the substrate W.

The radiation system comprises a source LA (e.g. an undulator or wiggler provided around the path of an electron beam in a storage ring or synchrotron) which produces a beam of radiation. This beam is passed along various optical components included in illumination system IL so that the resultant beam PB is collected in such a way as to give illumination of the desired shape and intensity distribution at the entrance pupil of the projection system and the mask.

The beam PB subsequently impinges upon the mask MA which is held in the mask holder on the mask table MT. Having been selectively reflected by the mask MA, the beam PB passes through the projection system PL, which focuses the beam PB onto a target area C of the substrate W. With the aid of the interferometric displacement measuring means IF and positioning means PW, the substrate table WT can be moved accurately, e.g. so as to position different target areas C in the path of the beam PB. Similarly, the positioning means PM and interferometric displacement measuring means IF can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library or during a scanning exposure. In general, movement of the object tables MT, WT will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1.

The depicted apparatus can be used in two different modes:

- In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto a target area C. The substrate table WT is then shifted in the x and/or y directions so that a different target area C can be irradiated by the beam PB;
- In scan mode, essentially the same scenario applies, except that a given target area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the x direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is

the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large target area C can be exposed, without having to compromise on resolution.

As shown schematically in Figure 2, projection system PL comprises a set of mirrors (reflectors) R1 to R4 which collect the exposure radiation reflected from (or transmitted through) the mask MA and focus it onto the wafer W. Further details of the optical design of this system are given in Gwyn et al. (referenced above) which document is incorporated herein by reference. This projection system PL requires mirrors that are thin, especially for mirror R1 which is very close to the wafer.

Suitable active mirrors 10a to 10c usable in the projection system PL are shown schematically in Figures 3A to 3C. Each mirror essentially comprises a mirror body 11 which provides mechanical support and rigidity, an active layer 12 including the actuators to control the mirror surface configuration and a multilayer coating 13 which forms the actual reflecting surface.

In current designs, the mirror body 11 is relatively thick, e.g. 25mm or more and up to a third of the lateral extent of the mirror, to avoid surface figure changes due to gravity and stress in the multilayer coating 13. However, by use of the present invention, this can be reduced substantially by using the active control to compensate for changes due to such effects. Preferred materials for the mirror body, whether thick or thin, are the glass, ULE (TM), Zerodur (TM) and aluminum and the body may be solid or, e.g., honeycombed as desired.

The actuator layer 12 is preferably embedded in the mirror body close to the multilayer 13 in order to have a direct influence on the surface figure. Figure 3A shows such an arrangement whereby the actuator layer 12 is placed between the mirror body 11 and multilayer 12 and has a flat form. The surface figure is formed wholly in the multilayer 13. Figure 3B is a similar arrangement but with the mirror body 11 and actuator layer 12 having a similar figure to the mirror surface figure. If it is not feasible to embed the actuator layer 12 in the mirror body 11, it can be attached to the bottom of the mirror body 11, as shown in Figure 3C.

Actuator layer 12 includes a suitable number and arrangement of actuators to effect the desired control over mirror shape; this is discussed further below. The actuators themselves may be of any suitable form and use any suitable actuating principle, e.g.

piezoelectricity, electrostriction, magnetostriction or by use of permanent magnet and coil, either moving magnet or moving coil.

Presently, piezoelectric actuators are preferred and, of piezoelectric materials, lead zirconium titanate (PZT) is preferred over polyvinylideen diflouride (PVDF). PZT has high force per unit mass, static force capability, high unconstrained strain/blocked force product, negligible DC resistance, relatively widespread availability, and flexibility in dimensions, materials and electrode configurations, which characteristics make it desirable for use in the present invention.

The actuators included in actuator layer 12 are preferably patch actuators, i.e. thin plate-like bending mode actuators which act as bimorph assemblies when attached to a plate. With such actuators the major principle by which curvature in the assembly is created is the in-plane forces generated in the piezoelectric material. Piezoelectric patch actuators usable in the invention include two major types: actuators in which the electric field is applied in the thickness, i.e. out-of-plane direction; and actuators in which the field is applied in the in-plane direction. One particularly suitable form of the latter type is the Active Fiber Composite (RTM) actuator manufactured by Continuum Control Corporation, Massachusetts, USA. The Active Fiber Composite (AFC) actuator comprises thin rods or fibers arranged in parallel to the in-plane direction with interdigitated electrodes. The distance between the electrodes is relatively large, requiring large voltages, but the capacitance of the actuators is relatively small so currents in operation are likewise small. AFC actuators are active only along their length and have a similar overall efficiency, expressed as the mechanical power delivered to a load divided by the reactive electrical input power, to conventional patch actuators. A particular advantage of AFC actuators in the present invention is their mechanical flexibility which allows them to be applied to surfaces with a relatively large degree of curvature.

The patch actuators used in the invention exert substantially all their operating force in the plane of the multi-layer 13. Since the multilayer 13 has higher in-plane stiffness than out-of-plane stiffness, this arrangement allows more accurate control of the surface figure since a given force will cause a smaller change in the surface figure. Thus the voltage applied to the actuator can be controlled with greater exactitude and any error, e.g. as a result of a non-linear voltage response of the actuator, will cause a smaller error in the surface figure.

The number size, and layout of actuators in the actuator layer 12 is dependent on the precise mirror construction, particularly its size and shape as well as the thickness of the mirror body and the nominal stress in the multi-layer 13. The required accuracy of the controlled surface figure is also important. As a starting point, actuators can be arrayed evenly across the mirror in a suitable regular array. However it is also possible to concentrate actuators in areas of the mirror where surface figure errors contribute disproportionally to wavefront errors or where greater surface figure errors are expected.

A control system for the active mirror of the invention is shown schematically in Figure 4; this control system is based on interferometer wavefront sensing and a zero reference interferogram, but other sensing principles and references may be employed. A laser source 21 outputs two coherent laser beams of suitable frequency. One beam is passed through the adaptive optical system 100 according to the present invention, e.g. projection system PL, before the two beams are recombined and interfere in interferogram detector 22. The output of interferogram detector 22 is compared to the zero reference interferogram *zri* by subtractor 23 and the difference supplied to fringe pattern analyzer 24 which provides wavefront information of the beam that has passed through the adaptive optics 100. Subtractor 25 subtracts this wavefront information from the desired wavefront information *dw* to generate the wavefront error *we* which is supplied to controller 26. Controller 26 in turn generates drive signals for the actuators of the adaptive optics 100 to minimize the wavefront error.

As alternatives to the above wavefront sensing arrangement it is also possible to sense the surface figure directly, e.g. using an interferometer to directly measure the surface figure via an array of points, or to measure the stress in the multilayer, since it is determined that this is the source of the error. Piezo-electric PVDF sensors integrated into the mirror at a suitable position may be used for this.

The control system for the active mirror can be operated in either on-line or off-line methods. In off-line methods, the actuation forces necessary to correct the mirror surface figures are determined at machine installation and periodically thereafter during maintenance of the machine. In the off-line control method, a recursive approach may be used, whereby a set of control signals is determined as an approximation to correct the surface figure; the wavefront aberration is then measured again and the control signals

adjusted to improve the correction. This procedure may be repeated through a number of iterations suitable to meet the necessary tolerances in the optical system.

An on-line control method enables real-time or quasi real-time correction of the mirror surface figures to compensate for changing environmental conditions, e.g. ambient temperature, which may change during an exposure or series of exposures and component drift. For the on-line control, an at-wavelength (i.e. operating at the exposure wavelength) interferometer may be integrated into the projection optics. This interferometer may measure the interferogram during convenient intervals of the exposure process, e.g. during wafer or mask exchange. The data from this can then be used to update the control signals to correct the mirror surface figure(s).

With the invention, it is preferable to control the optical system including the active mirrors as a whole, rather than controlling individual active mirrors separately. In this way errors of one mirror may be optimally corrected by adjusting the surface figure of another and surface figure errors of static mirrors included in the system may also be corrected. In this way it may not be necessary to provide all mirrors included in the system with actuators.

Examples

The following examples of the first embodiment of the invention are based on analysis of a 400mm x 400mm mirror on a 25mm thick mirror body of ULE and a multilayer of 1μm total thickness with a nominal stress of 400 MPa.

In the examples, piezo-electric patch actuators operating on the mirror in the in-plane direction are used. The actuator material is conventional PZT with a piezo constant of 166pC/N in both directions, an effective Young's modulus of 6.3×10^{10} Pa, a Poisson ratio of 0.3 and an effective thickness and electrode distance both of 0.19mm. Square patch actuators cover the entire surface of the mirror in a square array of 1, 9, 16, 25, 36, 100 or 400 actuators. A 10% sinusoidal variation in the nominal stress in the multilayer is assumed.

The results of the examples are shown in Figure 5. The first column shows the number of actuators, with the first row being a corresponding arrangement with no actuation for comparison. In column A, the rms surface figure error in nm is given. It can

be seen that even a single actuator gives a substantial improvement and that the rms error improves rapidly with additional actuators.

In column A the total error is given. It can be shown that for wavefront errors the surface figure can be decomposed into characteristic Seidel shapes of which piston, tip/tilt and focus are the lowest order terms. A mirror mount adjustable in 6 degrees of freedom can compensate for these low order terms. Accordingly, column B in Figure 5 gives results assuming that the piezoelectric actuators according to the invention only compensate for the higher order errors. As can be seen, if low order errors are corrected by the mirror mount, the comparison, without control, value is much improved, but the introduction of actuators according to the invention still results in significant improvements, increasing with the number of actuators.

Many projection systems will not make use of the entire mirror surface; assuming a 20% unused freeboard and low order correction via the mirror mount, results are given in column C of Figure 5. Again substantial improvements in surface figure are provided with increasing numbers of actuators.

Embodiment 2

In a second embodiment of the invention, which may be the same as the first embodiment save as described below, stack actuators acting diagonally are used.

Stack actuators used in the second embodiment of the present invention comprise rod-like actuators arrayed diagonally to the mirror surface and acting along their lengths. Though generally necessitating a bulkier construction than patch actuators, stack actuators can use multiple electrodes along their length to reduce the driving voltages and can be used if linear motion with large concentrated forces is required. Stack actuators also allow any surface figure to be controlled.

A mirror 30 employing stack actuators and used in the second embodiment of the invention is shown in Figure 6. In this mirror, two arrays of oppositely inclined actuators 31, 32 are connected diagonally between base plate 11 and the reflective member 33, which comprises a multilayer 13 provided on a suitable substrate. The angle of inclination, a, of the actuators is preferably less than about 60° and most preferably less than about 45°. At least in part of the mirror, the actuators 31, 32 are arranged in pairs so that two oppositely inclined actuators 31a, 32a are connected to the reflective member 33 at the same point.

With this arrangement, one actuator 31a can be arranged to exert an expansive force, fa, and the other actuator 32 a compressive force, fb, of equal magnitude so that the resultant force, fr, is wholly in the plane of the mirror. A similar effect can be achieved even where the angles of inclination of the actuators are not equal by suitable adjustment of the magnitudes of the forces applied.

In addition to the diagonal actuators, some perpendicular actuators may also be included, e.g. for compensating for perpendicular components of the forces exerted by the diagonal actuators. Combinations of patch, diagonal and/or perpendicular actuators may also be used.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention.

Claims

1. A lithographic projection apparatus for imaging a mask pattern in a mask onto a substrate, the apparatus comprising:

an illumination system constructed and arranged to supply a projection beam of radiation;

a first object table provided with a first object holder constructed to hold a mask;

a second object table provided with a second object holder constructed to hold a substrate;

a projection system constructed and arranged to image an irradiated portion of the mask onto a target portion of the substrate; and

an active reflector comprised in an optical system, being either or both of said illumination system and said projection system, said active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer; characterized in that:

said actuator exerts a substantial force component in a direction parallel to the surface figure of said reflective multilayer.

2. A lithography apparatus according to claim 1 wherein said actuator comprises a piezoelectric actuator.

3. A lithography apparatus according to claim 1 or 2 wherein said actuator is operative to apply forces to said active reflector such that the force component in directions perpendicular to the plane of said reflecting multilayer is less than 50% and preferably less than 20% of the total force exerted by said actuator.

4. A lithography apparatus according to claim 1 or 2 wherein said actuator is operative to apply forces to said active reflector substantially only in directions parallel to the plane of said reflecting multilayer.

5. A lithography apparatus according to any one of the preceding claims wherein said active reflector has a plurality of actuators arranged in a regular array.

6. A lithography apparatus according to any one of the preceding claims further comprising sensing means for detecting wavefront aberrations in a radiation beam reflected by said active reflector and a control system responsive to said detector for controlling said actuator to minimize said wavefront aberrations.

7. A lithography apparatus according to claim 6 wherein said sensing means comprises an interferometer for measuring the surface figure of said active reflector.

8. A lithography apparatus according to claim 7 wherein said sensing means comprises an interferometer functional at the wavelength of said projection beam of radiation.

9. A lithography apparatus according to claim 6 wherein said sensing means comprises at least one strain gauge for detecting strain in said reflective multilayer of said active reflector.

10. A lithography apparatus according to any one of claims 6 to 9 wherein said optical system includes a plurality of active reflectors said control system is operative to control said plurality of active reflectors together to minimize wavefront aberrations in said optical system as a whole.

11. Apparatus according to any one of the preceding claims wherein said projection beam comprises extreme ultraviolet radiation, e.g. having a wavelength of less than 50nm, preferably in the range of from 8 to 20nm, especially 9 to 16 nm.

12. A device manufacturing method using a lithography apparatus comprising:

an illumination system constructed and arranged to supply a projection beam of radiation;

a first object table provided with a first object holder constructed to hold a mask;

a second object table provided with a second object holder constructed to hold a substrate;

a projection system constructed and arranged to image an irradiated portion of the mask onto a target portion of the substrate; and

an active reflector comprised in an optical system, being either or both of said illumination system and said projection system, said active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer; the method comprising the steps of:

providing a mask bearing a pattern to said first object table;

providing a substrate having a radiation-sensitive layer to said second object table; and

irradiating said mask with said projection beam whilst imaging an irradiated portion of said mask onto said substrate; characterized in that:

said actuator exerts a substantial force component in a direction parallel to the surface figure of said reflective multilayer; and by the step of:

during said step of irradiating and imaging, controlling said active reflector to minimize wavefront aberration in a radiation beam reflected by said active reflector.

12. A device manufactured in accordance with the method of claim 12.

Abstract

Reflectors for use in Lithographic Projection Apparatus

In a lithographic projection apparatus, an active reflector comprising a body member, a reflective multilayer and at least one actuator controllable to adjust the surface figure of said reflecting multilayer is included in the illumination or projection optical systems. During imaging, the surface figure of the active reflector is controlled using the actuator to minimize wavefront aberration in a radiation beam reflected by the active reflector.

Fig. 4

Fig. 1

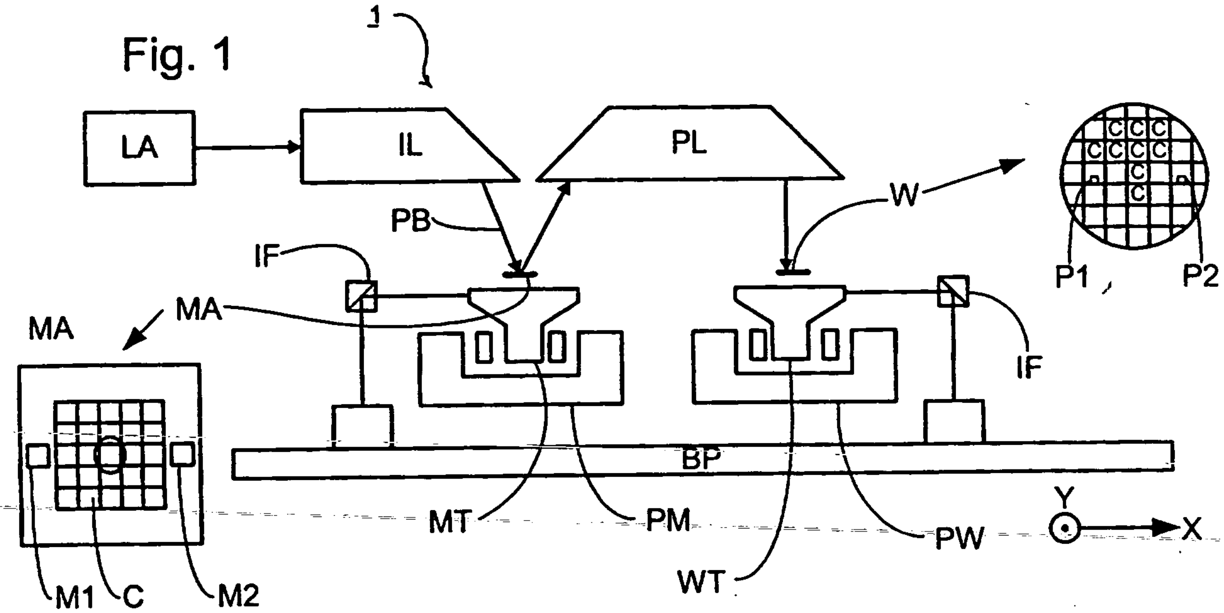

Fig. 2

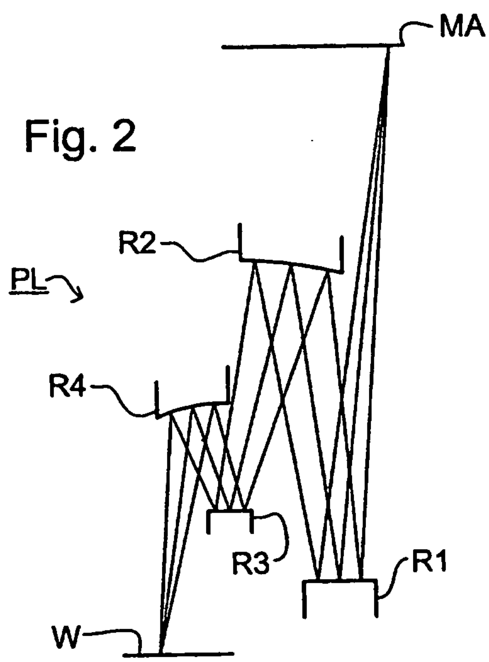

Fig. 3A

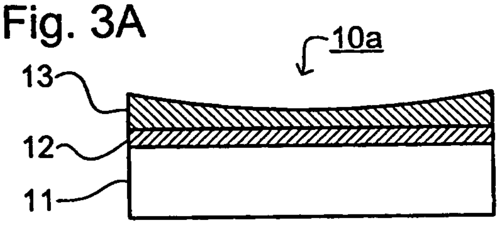

Fig. 3B

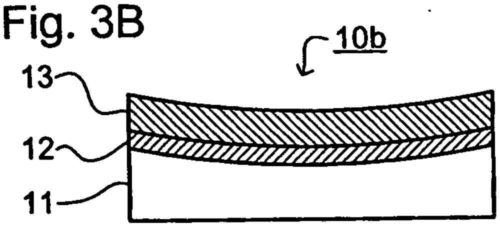

Fig. 3C

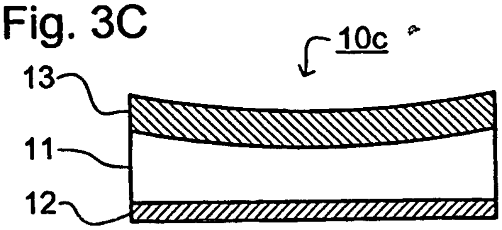

Fig. 4

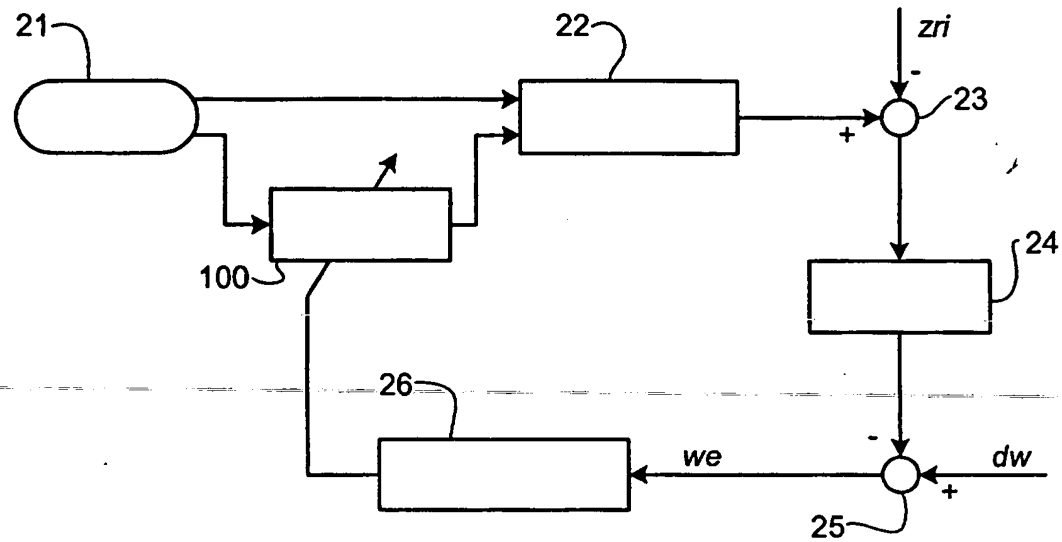

Fig. 5

	A	B	C
0	363	57.9	35.3
1	16	11.0	7.8
9	2.4	2.1	1.9
16	0.77	0.67	0.54
25	0.34	0.30	0.29
36	0.18	0.16	0.16
100	0.03	0.03	0.03
400	0.004	0.004	0.003

Fig. 6